

Riverine Hydrologic & Hydraulic Engineering Guidelines and Standards

Background

Hydrologic and hydraulic (H&H) riverine engineering studies, with respect to National Flood Insurance Program (NFIP) regulated streams, have a long history in the State of North Carolina. These studies have evolved from Map Modernization Phase I which primarily focused on the coastal plain and sand hills physiographic regions of the State, to Phase II and III study areas which focused on the piedmont, foothills, and mountains, to the subsequent rounds of map maintenance that further improved upon the available studies' scope and detail. The State is approaching a unique change in the way they store and distribute study-related material as they near implementation of the digital display environment.

Issue

This Engineering Issue Paper represents the compilation of past issues, engineering meetings, and current guidance/requirements for H&H studies. This paper compiles lessons learned from the history of flood studies performed by the NCFMP, aids the NCFMP in standardizing approaches to H&H studies, and will improve the efficiency of the review process.

Guidelines, Recommendations, and Requirements

Terrain Source

The bare earth LiDAR data is the primary source of topographic information. State or local data must exceed NCFMP LiDAR accuracy and requires pre-approval in order to be utilized. Existing LOMR topographic data should also be reviewed to determine if it qualifies as best available data and be incorporated if this determination is made.

The North Carolina Floodplain Mapping Program (NCFMP) has two terrain datasets that can be used depending on whether the terrain is used for subbasin delineation or mapping purposes. For subbasin delineation and/or discharge accumulation grid creation, a hydro-corrected 50-ft Digital Elevation Model (DEM) is available. A finer resolution 10-ft DEM is also available for floodplain mapping. Please coordinate with NCFMP to obtain the finer DEM developed from the latest Lidar terrain dataset for hydraulic analysis.

All elevation data, except NCFMP provided LiDAR data (FEMA approved source), used for H&H riverine analysis shall be sealed by a Professional Land Surveyor or Professional Engineer.

Hydrology

1. Use of Aerial Imagery to Estimate Impervious Surface – Review of impervious cover will focus on areas that will require hydrology be based on applying impervious cover results (i.e. basins modeled using urban regression equations). EMCs should ensure inclusion of large impervious surfaces such as parking lots that are not picked up with current methodologies.

The 2016 or more recent National Land Cover Database (NLCD) will be used as a reference and compared with delineated impervious areas. Any major discrepancies need to be explained in order to exclude impervious area. Aerial imagery viewed at 1:500 scale will also be used to determine if any additional areas of impervious cover should be added to the impervious cover calculation.

2. United States Geological Survey (USGS) Regression Hydrologic Regions – Area weight all regression discharges based on Hydrologic Region as defined in SIR-2014-5030 (USGS 2014) and SIR 2009-5158 (USGS 2009) for Urban and Rural regression equations, respectively. Use of the 'Blue Ridge-Piedmont' Urban equations from USGS Fact Sheet 007-00 (USGS 2002) may be applied for Hydrologic Region 2. When computing the additional profiles for effective models (model upgrades), use the regression equations consistent with the effective model.
3. USGS Regression Percent Impervious Threshold to Switch from Rural to Urban Regression – In general, use the following guidelines as recommended by USGS:

Use Southeast Rural SIR 2009-5158 (USGS 2009):

- a. Drainage Area that range in size from 1 mi² to 9,000 mi²
AND
- b. Impervious Area is less than 10%

Use Southeast Urban SIR-2014-5030 (USGS 2014):

- a. Drainage Area less than 1 mi²
OR
- b. Impervious Area is greater than 10%

Use USGS Fact Sheet 007-00 (USGS 2002):

- a. Drainage Area (in Hydrologic Region 2) between 0.04-41.0 mi²
AND
- b. Impervious Area is greater than 10%

Document variances from the above or case-by-case judgements in the hydrology report.

4. USGS Urban Regression Equations – A few guidelines/tips/requirements for USGS urban regression equations:
- a. For estimating percent impervious and developed, the 2016 National Land Cover Dataset (NLCD) should be used. The SIR 2014-5030 regression equations were developed using the 2006 NLCD, but the equations are suitable for 2011 NLCD (and newer).
 - b. Per USGS, gage weighting for an urban stream is not required but will be considered if gage data indicates weighting would increase stream discharge.
 - c. The USGS regions boundary shapefile is clipped at NC/VA state line. To confirm region areas in Virginia, one source is the online application, USGS "StreamStats" (http://water.usgs.gov/osw/streamstats/north_carolina.html)
 - d. A unique percent imperviousness will be calculated for each discharge point, when needed, for urban regression calculations.
 - e. If USGS Fact Sheet 007-00 is used for Blue Ridge urban areas (Hydrologic Region 2), the 500-yr urban regression the equation below will be used:

$$Q_{0.2\%} = 10^{(\log Q_{1\%} + (2.3 * (\log Q_{1\%} - \log Q_{2\%})))}$$

5. Flood Insurance Rate Map (FIRM) Modeling of Dams or Dam-Like Structures – When routing discharges, contractors are to follow the information contained within the FEMA guidance document, "Recommendation of an Interim Guidance Procedure for FIRM Modeling of Dams or Dam-Like Structures". This document is unavailable online but can be provided by NCFMP upon request.

Starting with FY 2013 NCFMP will provide or request EMCs provide, for NCFMP review, point shapefile of storage areas that meet Federal Emergency Management Agency (FEMA) guidance and can be applied to the discharge modeling. Until that time contractors should continue to model storage as they have been previously.

Localized flood routing for roadway embankments and railroads will be considered on a case-by-case basis. In general, if a structure's embankment is three (3) times its height (e.g. a 3-ft diameter culvert with an embankment that is 9-ft or more in height), the water surface elevation is at or overtopping the embankment top, and buildings are in the vicinity immediately upstream of the structure, then localized flood routing will be considered. Flood routing will be used to model the structure of interest and determine the regulatory water surface elevation upstream of the structure, but discharge reductions related to flood storage will not be applied downstream of the structure. If a structure is routed, the modeled storage area behind the structure must be mapped as floodway. This will in general result in a coincident floodway and SFHA boundary.

The suggested method of applying the routed backwater elevation for each profile in HEC-RAS is to generate a stage-discharge rating curve at the structure. Additional discharges should be added to a separate flow file to ensure the curve estimates discharges less than the 10-pct values. The structure should be modeled in the routing software (e.g. HEC-HMS) or spreadsheet using the HEC-RAS generated rating curve. HEC-RAS modeling regulatory water elevations shall match the corresponding routed values to within 0.00-ft and to within ± 0.1 -ft for non-regulatory profiles.

The HEC-RAS flow file used for mapping shall use only non-attenuated discharges.

To facilitate routing, the 10-pct through 0.2-pct discharges shall be converted into unit hydrographs using one of the two following sources. For urban conditions, "Estimating Flood Hydrographs for Urban Basins in North Carolina", WRRRI Report 69-4085. For rural conditions, there is not a regional study similar to that available for urban conditions. Use NOAA's "Unit Hydrograph (UHG) Technical Manual", source:
http://www.nohrsc.noaa.gov/technology/gis/uhg_manual.html

6. Hydrologic Discharge Rounding – All computed regression discharges will be rounded to three (3) significant figures (e.g. 12568 becomes 12500, 1587 becomes 1590, and 652 stays 652). Rounded discharge values in both HEC-RAS and regression calculation spreadsheets shall match.

HEC-HMS calculated flows should match their computed values.

7. Discharge Points for Hydrologic Modeling System (HMS) – Calculated discharges will be reviewed to confirm discharge points are placed so that conservative discharges can be computed and used for hydraulic modeling. Decreasing discharges will be avoided unless hydrologic routing has been performed and reviewed for appropriateness. Placement should consider incoming tributaries as well as significant reach routing that may occur over long reaches of stream segments. Major hydraulic structures are also locations that should be considered for discharge points.

Tributary flow and main stem flow should be isolated from each other at the confluence. Long reaches (e.g. > 0.5 mile) should be evaluated for potential additional basin breaks to ensure reach routing does not result in non-conservative flows being used for the hydraulic modeling.

8. Flow Assignment – The Figure 1 below is used to illustrate how flow assignments for discharge points will be assigned in HEC-RAS.

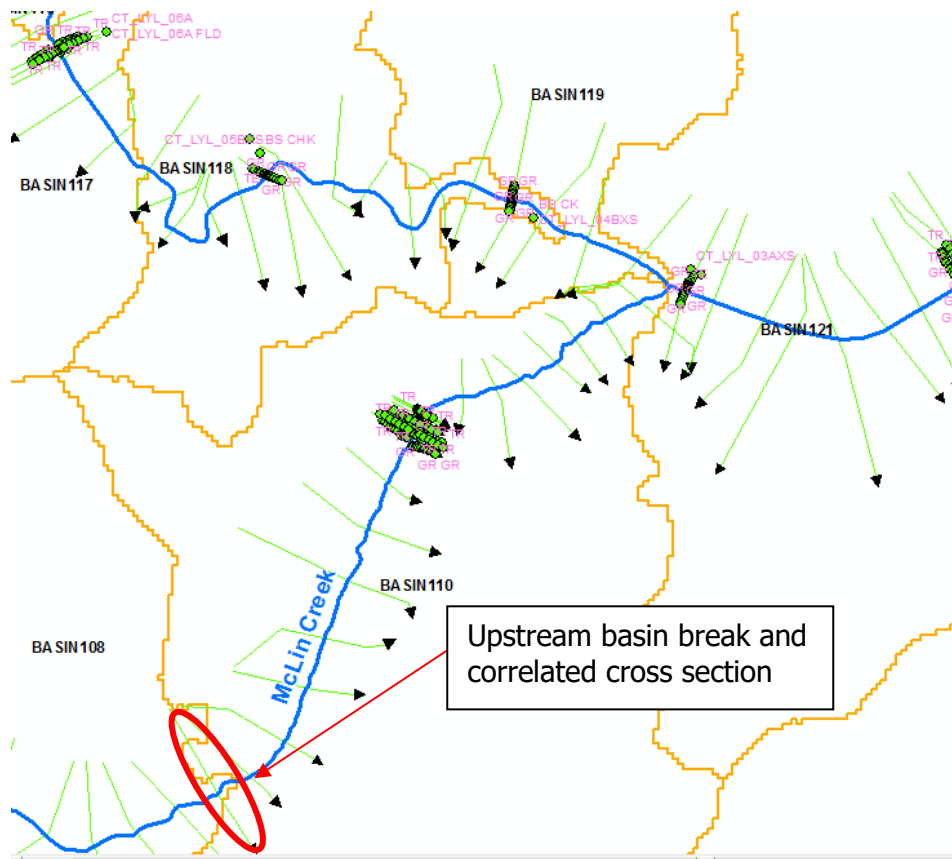


Figure 1. Example of HEC-HMS Flow Assignments

In the above example a discharge point is just above the confluence of the two streams shown for both reaches to create BASIN 110. This allows the main stem flow and tributary flows to be isolated from one another. The flows at the downstream end of BASIN 110 can then be input into the HEC-RAS model at the cross section circled in red that correlates to the upstream basin break. This ensures a conservative flow is utilized for hydraulic models when regression is used as the hydrologic methodology for developing the flows.

This process is similar when using HEC-HMS for hydrology, but reach routing and its impacts to discharges must be considered. In HEC-HMS it is possible that the discharge point would produce a discharge that is lower than what is produced at the upstream end of a particular reach. This can generally happen when a large basin is attached to the upstream end of a long reach in HEC-HMS and then only a small drainage basin is added at the downstream junction. In these instances, subbasin delineations need to be reconsidered and at a minimum flows need to be evaluated to verify that conservative flows are being used.

9. Gage Weighting – The range for gage weighting, in general, is from 0.5 to 1.5 times the gage drainage area (DA), but can sometimes be extended if surrounding gages support that the regional regression is under-predicting discharge. However, gage weighting should be terminated when regression discharges become larger than the weighted ones. In no instance will flows be attenuated in the downstream direction.
10. Adjustment Factors – In some instances there is sufficient localized gage data to support modification of the regional regression equations used for hydrologic computations. This can be done by developing and using what is known as an adjustment factor which will be applied to the regional regression equation flow estimates.

Whenever an adjustment factor is deemed necessary it will be discussed with NCFMP staff before implementation. Detailed calculations including units will be provided to support the use of the adjustment factor and will be documented in the hydrology report.

Hydraulics

1. HEC-RAS Model Naming Conventions and Profile Organization – Project (.prj) files, should be ≤ 23 characters and be unique for each stream. Specific naming guidance is as follows:
 - a. The type of study, whether it's a detailed or limited detail study, shall be included as part of the .prj file name. EMC's have included the type of study in the title name but NCFMP requests that this also be part of the .prj file name so that one can identify the type of study from the file name while viewing in windows explorer. For example, NCFMP recommends adding to the end of the Stream Name the study type naming conventions as follows:

DS for Detailed Study (i.e., Little River_DS)
LDS for Limited Detail Study (i.e., Little_River_LDS)
 - b. For long rivers where multiple studies have been completed, add the downstream boundary cross-section station to the end of the file name by rounding the river station to the hundreds. This is similar to the format used to number mapping cross-sections. For example, Little River model starting at cross section 13458 would be named "Little_River_135_DS"
 - c. River names should be ≤ 16 characters (including spaces) and be unique for each stream. When the river name needs to be shortened

to be ≤ 16 characters , NCFMP recommends using the naming conventions as follows:

- Rv for River
- Cr for Creek
- Br for Branch
- Tr for Tributary
- Un for Unnamed
- SF for South Fork (same convention for North/East/West Fork)

Our preference is the primary stream name not be shortened. For example, prioritize maintaining the "North Buffalo" part of North Buffalo Creek rather than shorting entire name to NBC. Also, when necessary, shorten the direction reference to meet the character limit before the trimming the unique name. (e.g. NBuffaloCr).

Complex naming situations may occur in western counties (e.g. UnTr1.1UnTr1BkCr). In instances where the above guidance is not adequate then a revised naming convention needs to be discussed and approved by NCFMP staff.

- d. The plan and profile naming conventions below should be followed.

For limited and detailed studies create the following plans:

- i. "Multiple Profiles" Plan
- ii. "Community Profiles" Plan (as required)

For limited and detailed studies, create the following discharge files with the assigned profile names and order:

- i. "Multiple" Profiles-
1pct, 1pct_FW, 10pct, 4pct, 2pct, 02pct, Fut10, Fut20, FutUlt
- ii. "Community" Requested Profiles (as required)-
1pct_FutUlt, 1pct_Fut10, additional profiles as required

For legacy model upgrades create the following new and separate plan:

- i. "GridMapping"

Although the discharge file will contain some duplicate data from the effective discharge file, create the following discharge file with the assigned profile name and order:

- i. "GridMapping"
1pct, 1pct_FW, 10pct, 4pct, 2pct, 02pct, Fut10, Fut20, FutUlt

2. HEC-RAS Common Modeling Standards/Issues/Concerns – Several HEC-RAS modeling standards/issues/concerns have been noted during hydraulic model review. The below list should be considered during the model build:
 - a. Surcharge – Should be ≥ 0.00 -ft and ≤ 1.00 -ft at all cross-sections. In some instances when this range cannot be achieved with reasonable effort then it can be documented and discussed with NCFMP. The accepted range will never be allowed to exceed that stated in the G&S of -0.09-ft to 1.04-ft.
 - b. Internal Bridge Surcharge – Should be ≥ 0.00 -ft and ≤ 1.00 -ft for all structures. See above section a. for deviations.
 - c. Drawdowns – Reasonable engineering judgment should be used to remove drawdowns from regulatory profiles; however, a tolerance of -0.09-ft is allowable. When drawdowns cannot be removed, details of the reasoning should be included in the report and a note for the cross section in HEC-RAS added that states, "This drawdown occurs at this cross section. The drawdown has been evaluated and determined to be acceptable for the purposes of this model."
 - d. Discharge files will be created with hydrology that has been rounded to three significant figures as noted in item number 6 under the Hydrology section of this document.
 - e. Modeling Guardrails, Bridgerails and Fences:
 - i. Model all guardrails/bridgerails and Jersey barriers as blocked out. Do not model the approaching guardrails that block $< 50\%$ of overtopping discharge.
 - ii. Guardrails over culverts that block $< 50\%$ of discharge do not need to be modeled. Guardrails over culverts that block $> 50\%$ of overtopping discharge are required to be modeled.
 - iii. All variations to this guidance must be documented in the report and will be evaluated independently.
 - iv. Fences parallel to the discharge are not modeled. Fences that may impede the flow are modeled if they block $> 50\%$ of the discharge and, using engineering judgment, will not be knocked down during the 1-percent event
3. Floodway Encroachment Offsets – When possible, floodway or non-encroachment stations should be offset from bank stations a minimum of 5-ft. This sometimes inhibits optimization and in some cases is not appropriate due to the incised nature of the stream being modeled. When a 5-ft offset from bank station cannot be maintained for one of the above stated reasons, it will be accepted as long as it is not set on the bank station location. In some cases it may be advantageous to evaluate bank station placement and possibly adjust their location based on engineering judgment.

4. Froude Numbers near 1 and Critical Depth Defaults – The NCFMP's HEC-RAS models are run as steady state subcritical flow models, cross sections with Froude Numbers ≥ 0.95 and critical depth defaults for the regulatory profile will be flagged during review. The issues should be resolved or at a minimum a note indicating how the issue was evaluated and addressed should be added to the HEC-RAS model.
5. Major Breaks in Topography or Extreme Stream Slope – As noted in the HEC-RAS user's manual, this model is limited to slopes up to 10%. In steep slope areas and areas with major slope changes the modeler needs to review the model closely for HEC-RAS defaulting to critical depth. If this is the case, an appropriate number of additional cross sections will be required so that at a minimum the resulting WSE can be mapped on the terrain used for modeling purposes (e.g. the WSE for a downstream cross section should not be $<$ the minimum ground elevation of the cross section immediately upstream). These situations will need to be evaluated on a case-by-case basis, but it is likely that more cross section will be needed.
6. Coincident Peak Analysis – Per FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix C (G&S): Coincident Peak Analysis is not performed and applied for Hydrology. If deemed necessary for hydraulics, under G&S criteria, a known water surface elevation will be used for the downstream boundary condition for the stream of interest.
7. Use of Survey Photos for Bridge/Culvert/Inline Structure Modeling – Models are to be verified with survey photos before submission. Any irregular data entries should be revised or have a note added to the HEC-RAS model addressing the irregularity. During engineering review, survey data will be compared to models for consistency.

Irregularities can include, but are not limited to:

- a. Multiple culvert openings with the same invert in photo but different in data collection.
 - b. Different upstream and downstream pipe materials/sizes (more conservative material/size will be used)
8. Bridge Skew- Bridge, piers and the bounded cross sections skew should be considered when skew is calculated to be ≥ 20 -degrees or ≤ 35 -degrees and can be applied in two ways when appropriate:
 - c. Manually entering the smaller skewed dimension.
 - d. Using the skew option in HEC-RAS.

It is recommended that the HEC-RAS skew option be used when it is appropriate to add skew to cross sections or bridges. Skew should not be applied to culverts.

HEC-RAS allows the user to set separate skew angles for the bridge deck and the piers. HEC-RAS assumes piers are solid under the entire bridge deck. If the piers are not solid, consider entering 0-degrees skew for the piers and/or increasing the low flow pier coefficient to account for the increased losses of the angled piers.

9. R-Factor (ratio of cut line length to RAS XS length) – This ratio should be 1.0 unless skew is applied to the cross section in the HEC-RAS model. If $R > 1.0$, then GIS cut line is longer than the local station-elevation data can populate unless skew has been applied to the cross section in the HEC-RAS model. If $R < 1.0$, then GIS cut line is shorter than the local station-elevation data.
10. Crossing Profiles – Crossing profiles are not allowed except within cross-sections 2 and 3 of a structure where a transition of flow regimes from super to subcritical flow may occur. Crossing profiles are allowed on effective model upgrade models. These models have additional profiles added but the model cannot be modified in order maintain effective BFEs.
11. Minimum Hydraulic Model Length – No hydraulic model will be less than five (5) cross sections even if this length exceeds the effective study.
12. Use of Digital Building Footprints to Model Blocked Obstructions –
 - a. In an urban environment include all buildings as blocked obstructions where a footprint intersects a cross-section cut line. In addition, depending on building density and orientation use engineering judgment to assign increased Manning's n rather than ineffective discharge areas within the portions of the cross-section where discharge is influenced by buildings unless the buildings truly cause ineffective flow. This avoids floodways being calculated too narrowly in urbanized areas. If Manning's n is adjusted, in hydraulic report cite reference sources used to determine adjustment value or explain reasoning. Ineffective areas downstream of large buildings may be used to represent the buildings' hydraulic shadow.
 - b. In a rural environment, use engineering judgment to model the effects of buildings. Keeping in mind each cross-section can be assumed to represent the average conditions of the stream within half the distance to the nearest upstream and downstream cross-sections. Depending on the conditions, several approaches may be used: 1) building footprints can be used to add buildings as blocked obstructions, 2) due to its small footprint a building may be excluded in model and/or, 3) Manning's n is increased to model the minor effects of building(s) in the area represented by the cross-section. A general description of the method/judgment used should be documented in the hydraulics report.

13. Survey Cross Section to LiDAR Terrain Tie-Ins – In some cases disconnects in modeled elevation data are noted where a surveyed or survey-interpolated cross section is blended with the overbank LiDAR elevation data. These disconnects should be documented in the HEC-RAS model and resolved by blending the LiDAR data to match the survey.
14. Bank Stations – Should agree with survey information unless engineering judgment has been used to modify location. If judgment is used it does not need to be documented in the HEC-RAS model.
15. Effective Information – A table should be included in the hydraulic report that summarizes on a stream by stream basis large differences (> or < 1.00-ft) in BFE from the effective study to the map maintenance study. This will ensure that all significant BFE changes have a cause identified for them that can be discussed with the community during outreach.
16. Maximum Submergence – The default value for maximum submergence on bridges has been revised to 0.98 in HEC-RAS 4.1. This issue is noted incorrectly in the HEC-RAS User Manual and should be noted for studies starting in FY '11.
17. Ineffective Areas – Permanent ineffective areas are not allowed. Modeling of off-line ponds, borrow pits and rock quarries may be modeled by adjusting the geometry to match the ponded water surface. A note will be placed in the HEC-RAS cross section if this action is taken.
18. Bridge Modeling Approach – Low flow methods should be selected to compute both Energy and Momentum using the highest energy answer. High flow methods should be set to pressure and/or weir. Also, based on guidance from the HEC Center, for bridges that have no piers and have significant drops (*i.e.* >1.0-ft) in elevations through sections 2 and 3 of the bridge, computing energy only for the low flow method can provide a more reasonable result. Special cases (*i.e.*, Perched or Low Water Bridges) or any other modeling method should be documented in the report.

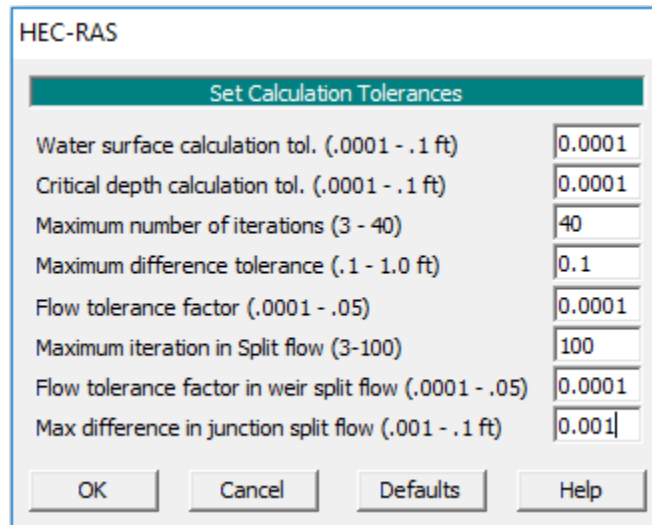
Reference: Per March 12, 2013 email to Dan Brubaker, NFIP Engineer, NC GTM, from Gary Brunner, Senior Technical Hydraulic Engineer, Hydrologic Engineering Center. USACE, "The momentum method in RAS is a 1D momentum balance. Its weaknesses are that it is 1D first of all, but also that it has to try to estimate a slope through the bridge in order to correctly account for the force do to the weight of water. Since you data set has about a 1.5 ft. drop in the invert from upstream to downstream, I don't think the momentum method is calculating this slope very well. You cannot simply take the slope of the lowest point in the cross section, when you have irregular cross section data, that does not work generally.

So my suggestion would be to use the energy method only for these bridges that have no piers and have significant drops in elevations through the bridge."

19. Structures/Utility Crossings – During scoping, NCFMP includes all structures that can be identified on the best available orthos at a 1 inch =500 feet scale and it is the EMC's responsibility to include these and any structures that are hydraulically significant. All structures viewable at this scale or located during contractor field survey should be included in the modeling. These structures may include but is not limited to the following:
- a. Bridges
 - b. Culverts
 - c. Foot bridges (Permanent with manmade embankments)
 - d. Pipeline Aerial crossings (18" or > in diameter)
 - e. Mill low head weirs
 - f. Dams
20. Decreasing Discharges in HEC-RAS Model – Decreasing discharges are not allowed unless routing was approved for hydrology. Decreasing discharges will not be allowed due to localized routing performed for item 5 in the hydrology section.
21. Reach Lengths – The stationing for any cross section should be the addition of stationing for the downstream cross section and the channel reach length between the two. Deviations from this will not be allowed. Overbank reach lengths should be based on the 1% annual chance floodplain.
22. Contraction and Expansion Coefficients – The contraction and expansion coefficients for sections 4, 3, and 2 around structures should be 0.3 and 0.5 respectively. All other contraction and expansion coefficients should be 0.1 and 0.3, respectively. Special care should also be taken when the upstream or downstream study limits are in the vicinity of a structure to ensure proper contraction and expansion coefficient are used.
23. Culvert Chart and Scale Numbers – Chart and Scale numbers identified in the HEC-RAS model should match what is indicated in the provided survey data forms. If a particular chart and scale does not exist in HEC-RAS then appropriate notes and descriptions should be added to the structure to avoid confusion and streamline the review process.
- Deviation for using the actual chart and scale number will be required from NCFMP as most culvert types can be found within HEC-RAS.
24. Depth Blocked in Culverts – Culverts are typically modeled as unobstructed based on the assumption that flows from lower recurrence interval (higher flow) storms would wash out any accumulated sediment that was not designed to be within the culvert opening. Culvert obstructions may be allowed if the culvert was designed to be buried to a specified depth or if other permanent obstructions that would not be washed out are identified

and documented. Culverts with sills at the upstream entrance may be modeled several ways depending on whether the culvert is operating under inlet or outlet control. If the culvert is modeled as inlet control, consider adding the height of the sill using the blocked obstruction variable or raise the floor elevation to reflect the decrease entrance cross-sectional area. For outlet control, the losses of the entrance do not directly govern the capacity of the culvert and are one of several calculated losses of the entire culvert, increasing the entrance losses may better account for sill impacts. A note shall be added in the HEC-RAS model to the structure of interest if the depth blocked option is utilized.

25. HEC-RAS Calculation Tolerances- Use the recommended HEC-RAS calculation tolerances shown in Figure 2 below. Use of these tolerances has been shown to reduce No-Rise and LOMC model issues of HEC-RAS calculating WSE changes significantly upstream of areas revised after the revised and effective WSE's had shown no difference.



Set Calculation Tolerances	
Water surface calculation tol. (.0001 - .1 ft)	0.0001
Critical depth calculation tol. (.0001 - .1 ft)	0.0001
Maximum number of iterations (3 - 40)	40
Maximum difference tolerance (.1 - 1.0 ft)	0.1
Flow tolerance factor (.0001 - .05)	0.0001
Maximum iteration in Split flow (3-100)	100
Flow tolerance factor in weir split flow (.0001 - .05)	0.0001
Max difference in junction split flow (.001 - .1 ft)	0.001

Figure 2. Recommended HEC-RAS Calculation Tolerances

26. Floodway Encroachments at Bridges-The general guidance for placing floodway encroachment stations for bridges is limit the encroachment stations to the edges of the bridge opening. This does not allow for any floodway encroachment within the bridge opening. There are circumstances when following this guidance will lead to highly unoptimized floodways because the opening limits the amount the floodway width can be reduced. One such example, is for a bridge with its deck above the floodplain, with only piers and no or a short section of embankment within the floodplain. For these conditions, the floodway encroachment should not be limited to the bridge opening but rather placed and optimized similar to cross-sections upstream and downstream of the bridge. This will map a consistent floodway through the structure without creating a very wide

floodway through the bridge and a narrower floodway upstream and downstream.

References

Issue Papers 42, and 44
NCFMP Engineering Meeting Minutes
HEC-RAS User Manual
HEC Center